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Test Operations Procedure	Drawbar Pull	Grassland Override
Mobility	Motion Resistance	Acceleration/Deceleration
Trafficability	Obstacle Test	Slope Negotiation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report fulfills the need for a document that establishes procedures for conducting mobility subtests in tropic environments. Facilities, instrumentation, test controls and data required are described, in addition to test procedures to be followed for conduct of the following mobility subtests: Soil tests: One-Pass Vehicle Cone Index, Drawbar Pull, Motion Resistance, and Acceleration/Deceleration; Surface Geometry Tests: Slope Negotiation and Discrete Obstacle; and Vegetation Tests: Single-Tree Override, Multiple-Tree Override and Grassland Override.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
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TROPIC TESTING OF VEHICLES

1. SCOPE

1.1 This TOP establishes procedures for conducting ground mobility subtests concerned with the interactions between the vehicle and soil, surface geometry, and vegetation in a humid tropic environment. These procedures can be applied with appropriate modifications to other environments.

1.2 The following vehicle mobility subtests are covered in this TOP:

SUBTESTS	CODE
Soil Tests	
One-Pass Vehicle Cone Index	A
Drawbar Pull	B
Motion Resistance	C
Acceleration/Deceleration	D
Surface Geometry Tests	
Slope Negotiation	E
Discrete Obstacle	F
Vegetation Tests	
Single-Tree Override	G
Multiple-Tree Override	H
Grassland Override	I

2. FACILITIES AND INSTRUMENTATION

2.1 Facilities

The tests established herein are to be conducted in the natural environment and the only necessary requirements are suitable test areas. Three test areas selected previously for tropic tests of vehicles are described in the following paragraphs. Table 1 summarizes the terrain characteristics. Other areas may be used for testing if they have similar characteristics and are consistent with the criteria of the tests being conducted. Specific details regarding test site parameters are provided in Appendix C.

Table 1. Test Site Characteristics

Test Area	Test Site	Grid Coordinate @Center	Size of Site (Hectares)	Soil Characteristics: Classification (USCS) 0-6 in	Soil Characteristics: Classification (USCS) 6-12 in	Soil Characteristics: Strength-Cone Index 0-6 in	Soil Characteristics: Strength-Cone Index 6-12 in	Slope (%)	Vegetation Characteristics[3]: Type[1]	Vegetation Characteristics[3]: Stem Density[2] (Stems/Hectares)	Vegetation Characteristics[3]: Height (Meters)	Type Test That Site Is Recommended For[4]
Gamboa A-1	A	400108	0.20	MH	MH-CH	225	300+	2	MxSG AdSG	-	15-20	G,H
"	B	398110	0.18	MH	MH	230	300+	2	MxSG AdSG	-	15-20	G,H
"	C	396113	0.23	MH	MH	280+	300+	2	AdSG	-	15-20	G,H
"	D	395117	0.80	MH	MH	220	300+	2	AdSG	-	15-20	H
"	E	391114	1.20	MH	MH	241	274+	0-10	GR MxSG	(30-250) -	2-2.5 10-15	G,H,I
"	F	300202	2.80	MH	MH	300+	300+	0-55	GR	(75-300)	2-2.5	B,C,D,E,F,I
Venado	G	530840	1.50	MH	MH	20-100	245+	2	-	-	-	A,B,C,D,E,F
"	H	540830	0.40	SM	SM	92	235+	0-10	-	-	-	A,B,C

[1]AdSG- Advanced Secondary Growth; MxSG- Mixed Secondary Growth; GR- Grasses; SP- Seasonal Swamp Palms; EG- Evergreen Variety Trees; SEG- Semi-Evergreen Variety Trees.

[2]For Grassland Areas the density is shown in parenthesis and is expressed in stems/meter^2

[3]At sites where only vehicular mobility tests are recommended, no vegetation data are shown. The site is either clear of all vegetation or contains only mowed grasses. At sites where only vehicle/vegetation interaction tests are recommended, the test site is covered completely by the vegetation shown. At sites where both type tests are recommended, portions of the site are covered by vegetation while others are clear.

[4]See para 1.1 for type of test.

2.2 Instrumentation. Instrumentation and accuracies/capacities required for mobility subtests are described below:

2.2.1 One-Pass VCI Test (Experimental)

Item	Capacity/Accuracy
Cone Penetrometer	300 psi; ± 10%
Soil Moisture/Density Sampler	2-inch (5 cm) diameter, thin-walled
Remolding Apparatus	Accuracy is determined by cone penetrometer

2.2.2 Drawbar Pull Test

Item	Capacity/Accuracy
Load Cell	Capacity depending on weight of test vehicle, ± 1%
Distance Measuring Device	± 1-inch per 100 feet (30 meters)
Wheel Revolution Counter	± 1/4 revolution
Data Recorder	Multichannel
Cone Penetrometer	300 psi; ± 10%
Remolding Apparatus	Accuracy is determined by cone penetrometer

2.2.3 Acceleration/Deceleration Test

Item	Capacity/Accuracy
Distance Measuring Device	± 1-inch per 100 feet
Timing Device	± 0.1 second
Speed Measuring Device	± 1 foot per second
Wheel Revolution Counter	± 1 revolution
Data Recorder	Multichannel

Cone Penetrometer	300 psi; ± 10%
Remolding Apparatus	Accuracy is determined by cone penetrometer

2.2.4 Slope and Obstacle Test

Item	Capacity/Accuracy
Cone Penetrometer	300 psi; ± 10%
Remolding Apparatus	Accuracy is determined by cone penetrometer
Transit or Theodolite	
Survey Pole	
Distance Measuring Device	± 1 inch (2.5 cm) per 100 feet (30 meters)
Abney Level	± 1/2 degree

2.2.5 Motion Resistance and Override Tests

Item	Capacity/Accuracy
Load Cell	Capacity depending on weight of test vehicle, ± 1%
Winch	Depends on magnitude of towing force anticipated
Cable	Same as above
Distance Measuring Device	± 1 inch (2.5 cm) per 100 feet (30 meters)
Cone Penetrometer	300 psi; ± 10%
Remolding Apparatus	Accuracy determined by cone penetrometer

2.2.6 Vegetation Override Test Items listed in paragraph 2.2.5 are used also for this test. In addition, a tape measure of 3 feet (1 meter) in length is needed to measure the circumference of the trees at breast height for computing the Diameter at Breast Height (DBH).

3. PREPARATION FOR TEST

3.1 Facilities. Based on previous methodology investigations,[1,2] test areas suitable for use in conduct of tropic tests of vehicles have been classified according to their suitability for use of tests described in the following paragraphs. Table 1 (para 2.1) summarizes the results of these investigations and should be used by test personnel in selection of optimum test sites. This, however, does not preclude selection of other test sites provided they have characteristics that are consistent with the criteria of the particular test involved. Appendix C defines the test site parameters. Factors to be considered in site selection are discussed below.

3.1.1 One-Pass VCI, (Experimental) This test is conducted to determine experimentally the minimum soil strength required for a ground crawling vehicle to negotiate one pass over fine-grained soil (clays and silts).[3] Soil strength is defined in terms of Rating Cone Index[4] in the critical layer which for most vehicles is at the 0-to-6-inch (0 to 15.2 cm) depth for VCI and 6-to-12-inch (15.2 to 30.5 cm) depth for VCI 5°. Thus, the RCI is the soil strength at which a vehicle can complete one pass and is the VCI_1 for that vehicle. The VCI can also be computed for one VCI_1 and 50 (VCI 5°) passes using the methods and techniques described in Appendix A.

3.1.1.1 Test sites should be selected with uniform soil strengths in and along the length of the test lane--the critical layer 0 to 6 inches (0 to 15.2 cm) and the underlying layer 6 to 12 inches (15.2 to 30.5 cm). Uniformity within the test lane can be determined after examining cone index data taken at several locations along the test lane. Test lanes should be level, free of heavy vegetation and surface irregularities, and at least 30.5 meters (100 feet) in length. A range of soil strength bracketing the computed VCI is necessary to experimentally establish VCI. For example, if the computed VCI_1 is 25, then the average RCI in the 0-to 6-inch (0 to 15.2 cm) layer of the test lane selected should range from 20 to 30 RCI.

3.1.1.2 To shorten testing time, test sites should have test lanes oriented so that the test vehicle proceeds from firm to soft soil until it is immobilized. Soil strength (CI and RCI) data are taken along both sides of the vehicle to determine the RCI at which the vehicle became immobilized.

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[1] Environmental Mapping of Tropic Test Sites, TECOM Project No. 9-CO-009-000-013

[2] Mobility in Natural Environments, TECOM Project No. 7-CO-RDT-TTI-015

[3] Experimental VCI is not determined for clean sands.

[4] RCI=Cone Index (CI) remolding index (Ri) for the same soil layer.

3.1.2 Drawbar Pull. This test is conducted to obtain data to determine the maximum drawbar pull that a vehicle can achieve on a given soil strength defined in terms of RCI for fine-grained soil and CI for coarse-grained soils (clean sands). The critical layer in both cases is the 0-to 6-inch depth. Previous tests have indicated that the optimum drawbar pull for most vehicles occurs at about 20-percent wheel or track slip, except for track vehicles which achieve their optimum pull at about 40-percent slip in coarse-grained soils. Several drawbar pull tests are conducted on a range of RCI's above the minimum required to support the test vehicle. From these tests, drawbar pull and soil strength relation is established. The maximum drawbar pull coefficient (drawbar pounds divided by the vehicle's test weight) that a vehicle can develop on a given soil strength closely approximates the tangent of the maximum angle that the vehicle can negotiate on the same soil strength.

3.1.2.1 Areas required for these tests are those in which 150 to 200 feet (45.7 to 61.0 meters) long test lanes can be established in smooth, level, relatively undisturbed surfaces free of heavy vegetation and containing a range of soil strength.

3.1.3 Motion Resistance. This test determines the force required to overcome the motion resistance of the test vehicle when operated over a range of soil strengths. Test lanes 100 feet (30.5 meters) long with uniform terrain conditions similar to VCI and drawbar pull tests are required. The test data are used to develop soil strength and motion resistance relations for the same soil types and strength ranges as for the drawbar pull tests. Usually they are conducted in the same test lane as the drawbar pull tests except that in the motion resistance test the vehicle is offset to straddle the ruts.

3.1.4 Acceleration/Deceleration This test determines the capability of a vehicle to accelerate and decelerate on a variety of surface conditions. Test lanes 100 to 300 feet (30.5 to 91.4 meters) are required, depending on the maximum speed a vehicle is expected to achieve before decelerating. For example, if the average RCI of the test lane is 20 points above the VCI, the test lane can be about one-half as long as if the test lane RCI were 100 points above the VCI. The soil and surface conditions required for this test are similar to the requirements described above for the drawbar pull test.

3.1.5 Slope Negotiation This test determines the slope performance of the vehicle for various surface conditions. It requires slope conditions that vary from shallow to steep, having uniform surface and soil strength conditions.

3.1.6 Discrete Obstacle. This test determines the capability of a vehicle to negotiate naturally occurring obstacles such as ditches, logs, mounds, and gullies. Suitable natural obstacles should be used and they should be selected so that appropriate approach and departure avenues can be prepared if necessary.

3.1.7 Tree Override. This test measures the amount of force required to push over and override trees of various stem diameters and branching structures. Approach lanes should extend into the jungle (figure C-11a), and be cut as required. During the single tree override tests, all undergrowth is cleared to allow easy movement and positioning of the vehicle, and to remove the resistive force produced by adjacent vegetation (figure C-11b). The jungle site chosen should have an ample number of trees with diameters at breast height of from 1 to 10 inches (2.5 to 25.4 cm). The surface of the site should be nearly smooth, level, and with sufficient soil strength to enable test vehicles to develop near maximum traction. The site should also allow ample room for positioning of test and winching vehicles. This is discussed in more detail in Performance Tests (paragraph 5).

3.1.8 Grassland Override This test is conducted in much the same manner as the Motion Resistance (para 3.1.3), but the basic difference is that the force above the level of motion resistance is a result of standing grass. Grass areas with 150 feet (45.7 meters) of smooth level lanes are needed. In tall grasses, visibility will limit the speed at which the driver will advance his vehicle; therefore, the length of the test lane can be reduced to 75 feet (22.9 meters). In overriding tall grasses they may become wrapped around the drive shaft causing some difficulty to light vehicles. In dry grasses the exhaust system could ignite a grass fire.

3.2 Equipment. Vehicles used in these tests should be loaded to the recommended cross-country payload, be in good electrical/mechanical condition, and have the recommended tire pressure for the type of terrain to be traversed. Other safety features considered necessary should be installed. Figure C-12 shows a protective cage installed over the driver for the tree override test. Tests should not be initiated until the engine has reached operating temperature.

3.3 Instrumentation. Proper calibration of each instrument should be insured prior to beginning each test. No additional instrument preparations are needed for the following tests: One-Pass VCI, Slope Negotiation, or Discrete Obstacle. Specific instructions are listed below for the remaining tests.

3.3.1 Drawbar Pull. Install the load cell in the cable between the test vehicle and the towed vehicle. Install the drive wheel or sprocket revolution counter on the test vehicle. Install the load cell amplifier and the line payout distance measuring device on the towed vehicle. Connect all devices to a multichannel data recorder in the towed vehicle where all data should be sequenced against an appropriate time-code generator.

3.3.2 Motion Resistance. Connect the load cell in the cable between the winching vehicle and the test vehicle. Place the load cell amplifier in the winching vehicle.

3.3.3 Acceleration/Deceleration. Install the drive wheel or sprocket revolution counter, line payout distance measuring device, time code generator, and multichannel recorder on the test vehicle. Connect each device to the multichannel data recorder.

3.3.4 Single-Tree, Multiple-Tree, and Grassland Override These test procedures are the same as for Motion Resistance (para 3.1.3).

3.4 Data Required

3.4.1 One-Pass Vehicle Cone Index After selection of a suitable test lane, in accordance with instruction in One-Pass VCI (para 3.1.1), collect soil samples before traffic for laboratory analysis and record the following along the test lane.

TYPE OF DATA	SAMPLE POINTS	PURPOSE
Soil sample from the 0-to 6-inch (0 to 15.2 cm) soil layer	two	Determine soil classification according to USCS
Soil sample from the 0- to 6-inch (0 to 15.2 cm) in soil layer	two	Determine soil moisture content
Soil sample from the 1- to 5-inch (2.5 to 12.7 cm) soil layer	two	Determine soil moisture content and density
Cone Index	Every 10 feet (3 m) at 1-,2-,3-,4-,5-,6-, 9- and 12-inch depths	Determine soil strength data in expected vehicle tracks
Soil sample at the 0- to 6-inch (0 to 15.2 cm) soil layer	two or three	Establish RCI for for the test lane remolding index at the lowest CI stations in the test lane

3.4.2 Drawbar Pull No soil data are collected before traffic. It is recommended to conduct the test run first, then measure the "before traffic soil data" adjacent to the ruts where a good record of maximum drawbar pull can be obtained. Rating cone index, moisture content and

density determination are required for the 0- to 6-inch (0 to 15.2 cm) depth. Samples are required for laboratory analysis of soil classification for the same soil layer.

3.4.3 Motion Resistance No pretest measurements are required. Soil data should be measured after the vehicle tests adjacent to the site where good stable record of force required to tow the vehicle was obtained.

3.4.4 Acceleration/Deceleration No data need be recorded prior to actual test execution. As in Drawbar Pull above, soil data are taken in a section of the test lane that represents the soil conditions in which the test was run.

3.4.5 Slope Negotiation Measure and record the slope along the test lane. The maximum angle that the test vehicle can negotiate the prevailing soil conditions should be determined by available maximum drawbar pull-soil strength relations for the appropriate soil type. This is the angle formed between a line passing through the center of gravity (CG) of the vehicle which is perpendicular to the ground, and a line that passes through the CG to the point on the ground which is perpendicularly beneath the center of the rear axle. This angle is computed as the arctangent d/h where h is the vertical distance from the ground to the CG, and d is the horizontal distance along ground from the point beneath the rear axle and the point perpendicularly beneath the CG. At no time should the slope of a test lane exceed this angle since the test vehicle will probably not negotiate it. The terrain descriptions would include the surface roughness, vegetal cover, and any other condition that may impede the progress of the test vehicle on the slope.

3.4.6 Discrete Obstacle Detailed profiles of all obstacles for a distance of 20 feet (6.1 meters) on each side of the obstacle should be recorded, e.g., depth of ditches, height of logs and rocks, and slope and height of mounds, using standard surveying techniques. Soil sample measurements should be collected in accordance with paragraph 3.4.1 above, and a photographic record maintained of each obstacle.

3.4.7 Single-Tree Override Record measurements of the DBH of each tree to be challenged (figure C-13b, above) and the cone index and remolding index of the 0- to 6-inch (0 to 15.2 cm) layer, if the soil is fine-grained (figure C-13a). Bulk soil samples should also be taken for the 0- to 6-inch (0 to 15.2 cm) layer for classification and moisture content determination. Record the vehicle identification, bumper height and ground clearance to the nearest 1/2-inch (1.2 cm), and test weight to the nearest 100 lbs.

3.4.8 Multiple-Tree Override Record the data prescribed in paragraph 3.4.7 above, to include measurements of each tree in the path of the

vehicle. Also record the distance in inches between each tree and the relative position (x,y coordinate) of each tree. Heavy vines should be included in these measurement records.

3.4.9 Grass Override Record the soil parameters outlined in paragraph 3.4.1. In addition mark off several 0.9 meter (1-yard) squares (outside the expected vehicle path) and measure stem height and density (stems/yd^2).

4. TEST CONTROLS

4.1 Vehicle Mobility Subtests These tests should not be conducted during or immediately following rains because tropical clay soil surfaces are slippery when the surface containing free water which will minimize traction and invalidate test results. Moreover, all vehicle operators involved in testing should be experienced drivers to minimize possibility of driver influence.

4.1.1 One-Pass Vehicle Cone Index A sufficient number of tests should be conducted on soft soils with a uniform mass soils strength to accurately bracket the go, no-go performance. All tests should be conducted with the vehicle's front differential engaged (if applicable) and with the vehicle being driven through the test lane at an extremely low speed of approximately 2 miles-per-hour(3.2 kilometers per hour). In the event of immobilization, the driver should obtain assistance from a retrieving vehicle. If immobilization occurs with little or no sinkage and the underlying soil is firm, the immobilization was probably caused by surface slipperiness. Such an immobilization is not acceptable in determining VCI. Firm clay soils overlain by a thin wet surface layer (vegetation, organic matter, mud, free water) should be suspect for VCI tests because of potential slippery conditions.

4.1.2 Drawbar Pull The maximum drawbar pull should be maintained at a constant slip for at least a vehicle length and repeated a minimum of three times on each soil strength tested. The test should be repeated on a sufficient number of soil strengths to establish a drawbar pull soil strength curve. The vehicle should be driven in its lowest gear with drive wheel or track speeds of 2 to 3 miles-per-hour (3.2 to 4.8 kilometers-per-hour). It is important that slippery areas be avoided in this test because immobilization caused by slipperiness yields invalid results.

4.1.3 Motion Resistance This test is repeated a sufficient number of times in test lanes of various soil strengths to produce an adequate motion resistance soil strength curve. The test vehicle should be in neutral gear, engine not running, and be towed at a speed of 2 to 3 miles-per-hour. A reasonably constant force should be measured for at least three vehicle lengths. In addition to tests conducted in soils, the motion resistance on a firm, level surface, such as a paved road, should be measured. The difference between firm surfaces and pull motion resistance is attributable to the soil.

4.1.4 Acceleration/Deceleration This test should be repeated at least five times on both hard and soft soils. Surface conditions must be uniform for each test, be free of obstacles, and virtually free of vegetation. The test area should be large enough to permit the vehicle to develop its top speed from a standing start and then coast or be braked to a stop.

4.1.5 Slope Negotiation The test should be negotiated on slopes on which the vehicle becomes immobilized, because surface conditions strongly influence test results. Only the lowest gear of the test vehicle should be engaged for the test.

4.1.5.1 Maximum slope negotiation tests as described do not always follow the same pattern. Often measurements will *apparently* show the immobilization slope to be less steep than the negotiable slope. Moreover, one test may indicate that the vehicle can climb a certain slope and another test indicate that an even *steeper* slope was climbed on *softer* soil. These anomalies are the result of small abrupt changes in the slope, surface roughness, pot holes, rocks or debris; or they could be the result of failure to measure soil strength properly. As a precautionary measure to aid in analyzing results, the attitude angle of the immobilized vehicle itself, i.e., the true slope it is attempting to climb, should be measured because it may be steeper than the natural slope immediately adjacent. This is caused by rutting at the rear of a vehicle on a slope which is usually deeper than rutting at the front. The vehicle should not be allowed to spin its wheels or tracks for too long a time, or the attitude angle may reflect an erroneous slope.

4.1.5.2 An estimate of the maximum slope a vehicle can negotiate, for a given soil strength, may be obtained by referring to the appropriate maximum drawbar/slope-soil strength curve, if one is available. Estimates for maximum slope negotiable can be obtained for conventional wheeled and tracked vehicles from the drawbar pull coefficient-RCI relations shown in figure 1. For example, a tracked vehicle with greater than 4psi ground pressure can, on an excess RCI of 20 (VCI, +20), develop a drawbar of 54% of the vehicle weight or negotiate a maximum slope of 54%.

4.2 Vehicle/Vegetation Interaction Tests These tests will not be conducted during rains or for a period of six hours after rains have occurred. Several operators should be used in the tests to minimize individual driver influence on test results. In the single-tree failure and override tests, be sure that sufficient vegetation has been cleared from around the tree being failed to permit it to fall without becoming tangled in surrounding vegetation.

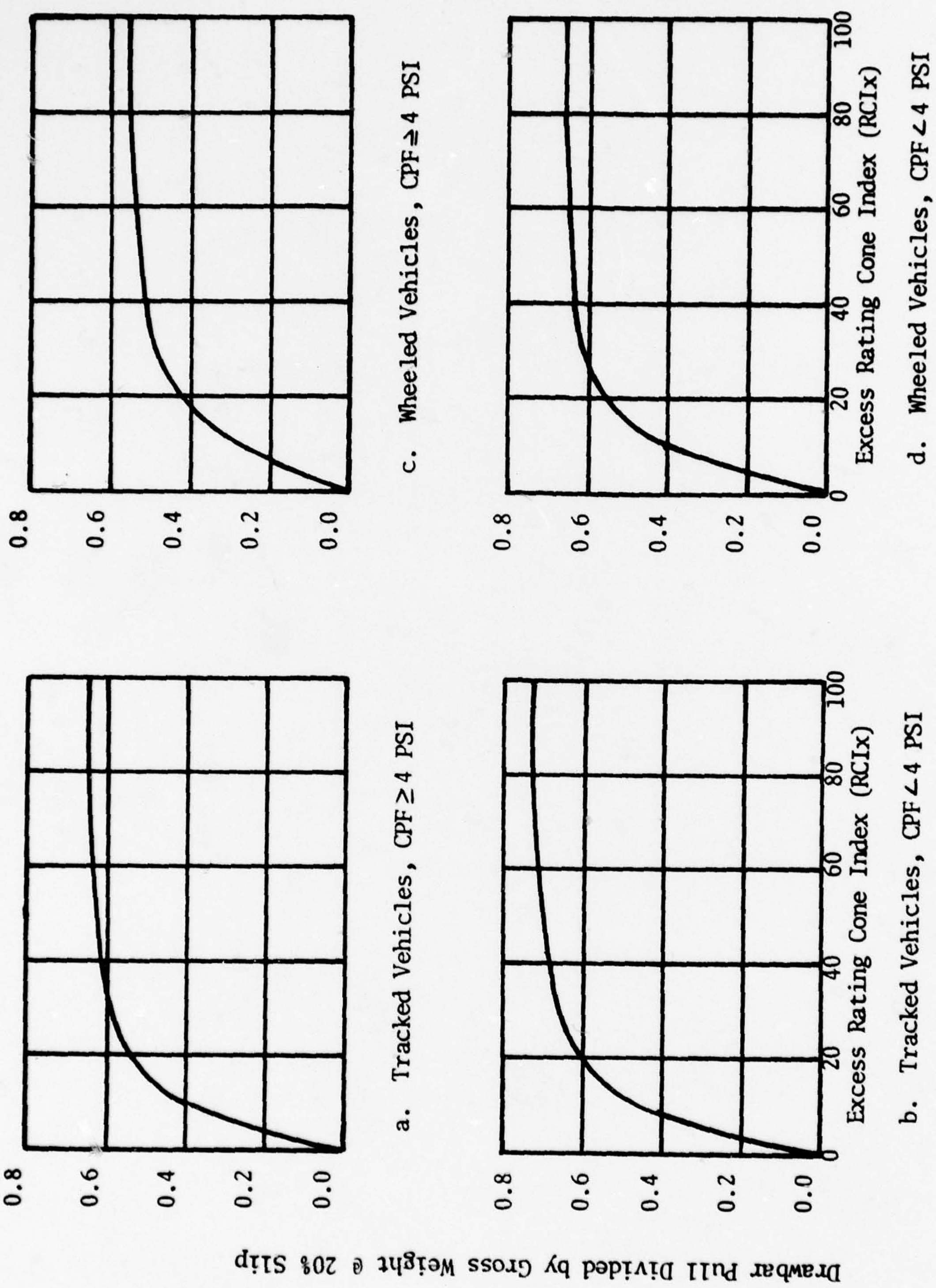

Figure 1. Drawbar Pull-Excess RCI Curves for Wheeled and Tracked Vehicles

5. PERFORMANCE TESTS

5.1 One-Pass Vehicle Cone Index

5.1.1 Method The driver engages the front differential (if applicable) and drives the vehicle through the test lane in the lowest gear at an extremely low speed of approximately (3.2 kilometers (2 miles) per hour. In the event of immobilization, the driver of the vehicle should be instructed not to attempt to move the vehicle by applying additional power, but to disengage the power train immediately and turn the ignition to the OFF position.

5.1.2 Data Required No additional data, other than procedures set forth in paragraph 3.4.1 above, are required. A typical data collection form is shown in table A-1.

5.2 Drawbar Pull

5.2.1 Method A drawbar pull slip test is performed by attaching a load vehicle to the test vehicle through a cable and load cell, then determining pull for a range of slips. If maximum drawbar pull only is required, then by trial and error find the maximum sustained load the test vehicle can pull in lowest gear while the traction element is travelling at a speed of 3.2 to 4.8 kilometers (2 or 3 miles) per hour. Pull is varied by changing the resistance offered from the load vehicle through braking it by increments, or by operating it in various gears (including reverse, in some cases) at different engine speeds. The exact process of finding the proper load will depend on the test vehicle, the load vehicle, the condition of the soil, and the skill of the vehicle operators. Some trial and error methods are necessary even for the best vehicle test operators. As in the case for VCI, it is important that the proper soil strength be associated with the test results, i.e., the maximum drawbar pull. It is also important that slippery areas be avoided, because immobilization caused by slipperiness yields invalid results, The collection of valid soil data is done most efficiently by *first* running the vehicle test, noting exactly the length of path in which the maximum drawbar pull occurred (wheels or tracks will be slipping at about 20 percent), and *then* measuring the required soil data in the immediate vicinity in locations undisturbed by the vehicle (not in the actual vehicle tracks). The actual number of tests is left to the judgment of the test officer, but there should be enough to sufficiently define the maximum drawbar pull-soil strength curve. The testing process may be simplified by the knowledge that the arctangent of the maximum slope attainable (Slope Negotiation), multiplied by the vehicle gross weight, is a close approximation of the maximum drawbar pull. Also, the One-Pass VCI is the abscissa value at zero drawbar pull on a maximum drawbar pull-soil strength curve.

5.2.2. Data Required The same type of soil measurements should be recorded as listed in paragraph 3.4.1 for the One-Pass VCI Test. The number of such measurements is left to the judgment of the test officer. A recommended policy is to record too many measurements rather than too few. About 20 sets of cone index readings and two to three remolding indexes should be sufficient. In addition, the following data should be collected for each test with a multichannel recorder: load cell measurements; distance vehicle travelled while sustaining maximum pull, and number of wheel revolutions for computation of slip. Table A-1 illustrates the data collection form to be used for soil data. The date, driver's name, vehicle type, and location should be noted on the multichannel recording.

5.3 Motion Resistance

5.3.1 Method The driver of the test vehicle should place the vehicle in all-wheel drive and shift the transmission into neutral. The vehicle is winched for a distance of 15.2 to 30.5 meters (50 to 100 feet) while recording the towing force on the load cell. This test should be repeated three or four times to determine an average motion resistance for a given soil strength.

5.4 Acceleration/Deceleration

5.4.1 Method The tests are conducted in 61 meters (200-foot) long test lanes with uniform surface conditions. To obtain a wide range of surface conditions, several different test lanes should be laid out in terrain with level surface conditions. Two tests are conducted as follows:

5.4.1.1 During the first test, the driver places the test vehicle in lowest gear and with full throttle begins a self-propelled, straight-line traverse of the test lane. From an initial standstill (zero speed) condition, the driver continues shifting gears (rapidly, as if drag racing) as he traverses the test lane until a predetermined point in the lane is reached. At this point, he rapidly disengages the power train and the vehicle is allowed to roll to a stop.

5.4.1.2 During the second test, the same test lane is used; however, the vehicle is moved laterally one-half of the vehicle's width but the path is parallel to that used in the first test. The second test run is conducted in the same manner as the first, except instead of disengaging the power train and allowing the vehicles to roll to a stop when the predetermined point in the test lane is reached, brakes are applied and the vehicle is stopped as rapidly as possible (panic-brake condition).

5.4.2 Data Required For each test lane, soil parameters should be measured just outside the vehicle tracks, as outlined in paragraph 3.4.1. Continuous recordings should be made of the following, using the techniques indicated:

Duration of Run - Measured from time event markers on the oscillograph recorder

Total Distance Travelled - Measured by means of a payout line

Revolution of Wheels - Measured by means of a magnetic reed switch mounted on the drive shaft

5.5 Slope Negotiation The soil data collection form in table A-1 should be used to record soil data with all other data recorded on the multichannel recorder. The date, type of test, location and name of driver should be noted on the record.

5.5.1 Method This test is conducted by running the test vehicle up a slope in its lowest gear. If the vehicle is immobilized, the portion of the slope immediately behind the vehicle is considered to be negotiable and the steeper portion around the immobilization point is considered not negotiable. The maximum slope negotiable (the value of interest) is assumed to be half-way between the two portions.

5.5.1.1 Tests with the definitive results described above do not always follow the same pattern. Often measurements will appear to show the immobilization slope to be less steep than the negotiable slope. Moreover, one test may indicate that the vehicle can climb a certain slope and another test indicate that an even steeper slope was climbed on a softer soil. These anomalies are the result of small surface irregularities in the slope or failure to measure soil strength properly. As a precautionary measure to aid in analyzing results, the attitude angle of the immobilized vehicle itself, i.e., the true slope it is attempting to climb, should be measured because it may be steeper than the natural slope immediately adjacent.

5.5.2 Data Required Soil data are collected to determine the soil type and soil strength (CI and RI) in areas adjacent to the immobilized test vehicle. The attitude angle of the vehicle is measured by means of pre-establishing two reference points on the test vehicle, so that a line drawn through them when the vehicle is on level ground will also be level. Therefore, the angle between the horizontal and the line through the two reference points while the vehicle is immobilized is the attitude angle. Table A-2 illustrates a data collection form for use with slope tests.

5.6 Discrete Obstacle

5.6.1 Method This test is straightforward: Each obstacle is challenged by the test vehicle at approximately 3.2 kilometers (2 miles) per hour.

5.6.2 Data Required If an immobilization occurs, the nature of the immobilization is described as bumper drag or approach angle too steep. In addition, a profile should be made of the obstacle encountered, as described in paragraph 3.4.6.

5.7 Single-Tree Override

5.7.1 Method This test is conducted in two parts:

5.7.1.1 Single-Tree Failure The cable from the winching vehicle is connected to the front bumper of the test vehicle through a V-shaped arrangement that permits an even pull on both shackles of the front bumper without interfering with the failure of the tree. The test vehicle is placed in a position so that its front bumper is against the tree (figure C-14). The driver of the test vehicle places the vehicle in all-wheel drive and puts the transmission in neutral. The test vehicle is then winched until the tree fails because of root or stem failure, or until the tree is pushed down by bending. At this point the tree is considered failed and the winching action is stopped. During the winching action, continuous recordings of forces exerted through the load cell are made with the load cell amplifier and chart recorder.

5.7.1.2 Single-Tree Override This second part commences after marking the end of the first part on the chart recording. The winching action is initiated again, and recordings are made of the forces being extertable through the winch cable until the test vehicle has cleared the branches of the failed tree. NOTE: When a tree fails, it may fall on the winching cable and cause non-related forces to be measured erroneously while the operator is trying to winch the test vehicle across the failed tree. If possible, the cable should be removed from the test vehicle and re-routed through the branches to prevent measuring the force required to pull the cable through the branches.

5.7.2 Data Required In addition to the data listed in paragraph 3.4.7, the following should be recorded for each challenged tree:

Continuous force measurements during winching action

Species of tree

Mode of tree failure (stem breaking, stem bending without breaking, root failure, uprooting, etc.)

Abnormal vehicle configurations (root structure of tree caught under carriage, wheel(s) off the ground, vehicle damage, etc.)

Table A-3 shows a data collection form suitable for use in conduct of the single-tree override test.

5.8 Multiple-Tree Override

5.8.1 Method The positioning and winching of the test vehicle in this test are the same as described for single-tree override. Test sites used in this phase of testing are selected with tree sizes appropriate to the vehicle being tested, as determined by single-tree failure results. The primary difference between the single and multiple tree tests is that, in multiple tree tests failing of any one tree is complicated by interference of crown entanglement and vines of neighboring trees.

5.8.2 Data Required Data required are the same as prescribed in paragraph 5.7.2 above.

5.9 Grassland Override

5.9.1 Method The test vehicle is winched through an undisturbed grass area while force measurements are recorded on a chart recorder through the load cell and load cell amplifier. At the end of the path, the vehicle s returned to the starting point and again winched through the same path with the grass cleared by cutting if necessary. Forces are recorded again and the differences of forces to override grassland.

5.9.2 Data Required In addition to the data collected, as shown in paragraph 3.4.9, the forces required for the vehicle to penetrate the grassland are recorded. Table A-1 illustrates the data collection form to be used for soils. Stem density, type of vehicle, location, date, and name of driver should be recorded on the recorder.

6. DATA REDUCTION AND PRESENTATION.

6.1 One-Pass Vehicle Cone Index Data to determine the VCI must include test results of both go or no-go conditions associated with a rating cone index for fine-grained soils and sands with fines poorly drained, or cone index for clean sands. If a vehicle becomes immobilized, only soil strength data measured along the vehicle path in undisturbed soil

in the immediate vicinity of immobilization should be averaged and associated with no-go conditions. In the case of a "go" along a test course which is obviously stronger in, for example, one-half the course than the other, the analyzer will determine the strength that represents the weaker end and associate that strength with the go test.

6.1.1 After the RCI has been determined (table A-1), a plot is made of the RCI values obtained for the go and no-go tests along a horizontal line (no ordinate is required) as shown in figure 2. As in figure 2, an absolute value of VCI could be determined experimentally if a sufficient number of go, no-go tests were conducted near the VCI. From a practical viewpoint, however, the test officer is restricted in the range of soil strength values that he can locate within the test areas available to him. He must locate test lanes so the soil strength range will minimize the difference in soil strengths that permit the vehicle go, no-go conditions illustrated below.

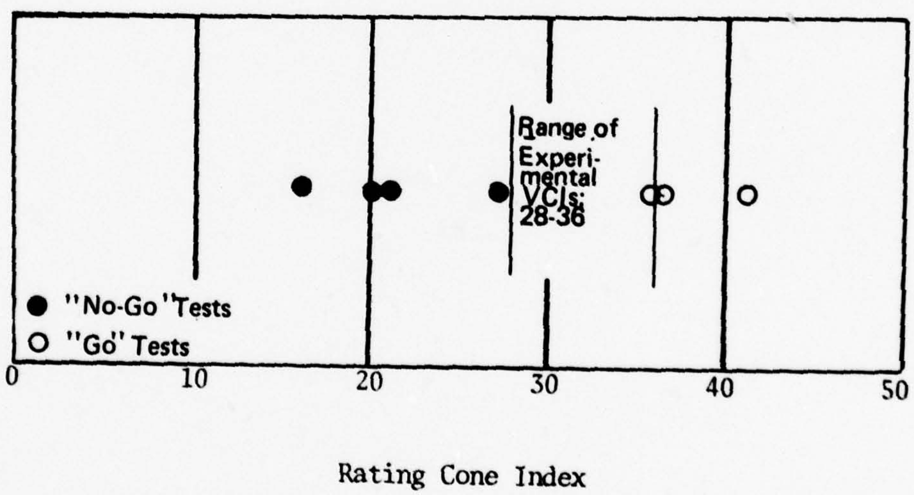

Figure 2. Example of Graphic Determination of Experimental VCI

6.2 Drawbar Pull This series of tests is conducted to define a maximum drawbar pull-soil strength curve. The drawbar coefficient, is a very close approximation of the tangent of the maximum angle that the vehicle can negotiate in the same soil conditions. The testing process may be aided by the knowledge that a curve of maximum drawbar pull/weight, or maximum slope versus soil strength plotted in terms of excess RCI, goes through the origin and assumes a characteristic shape as in figure 1. Contact Pressure Factor (CPF) is computed for tracked vehicles by dividing gross vehicle weight by the area of tracks in contact with the ground. CPF for wheeled vehicles is computed according to the following formula:

$$CPF = \frac{\text{Gross vehicle weight, pounds}}{\left[\begin{array}{l}\text{nominal tire}\\ \text{width, inches}\end{array}\right] X \left[\dfrac{\text{outside diameter of tire, inches}}{2}\right] X \left[\text{number of tires}\right]}$$

If the curve developed by tests deviates significantly from the pertinent curve in this reference (figure 1), the test curve is possibly in error and the test officer should reevaluate the procedures being used.

6.3 Motion Resistance-Soil Strength The chart recordings show a continuous record of the force required to tow the vehicle. These forces should be averaged and then plotted against soil strength to produce a motion resistance soil strength curve.

6.4 Acceleration/Deceleration To analyze the data obtained in this test, the time-distance recordings must be examined. A portion of a typical recording is shown in figure 3. [NOTE: When the test vehicle is moved into position on the test lane for the start of a test run, it is moved forward a foot or so to such a position that when the vehicle starts to move the channel 1 (distance) and channel 2 (drive-shaft revolution) event markers activate and mark the position on the oscillograph recording. In order to accomplish this, the switches for CH1 and CH2 must be synchronized. If this is not done, important information regarding maximum acceleration may be lost.] For illustrative purposes, the portion of the recording has been selected that represents the time when the test vehicle reached maximum velocity and then began to roll to a stop (decelerate). The recording is analyzed in the following manner:

6.4.1 Knowing the frequency of the reference time markers, the chart can be subdivided into time intervals as indicated on the bottom of the chart. For the major portion of the recording used for illustrative purposes (the time when the test vehicle reaches maximum velocity and then begins the roll to a stop), analysis of the recording at time intervals of once each 1/2 second is sufficient. In the earlier portions

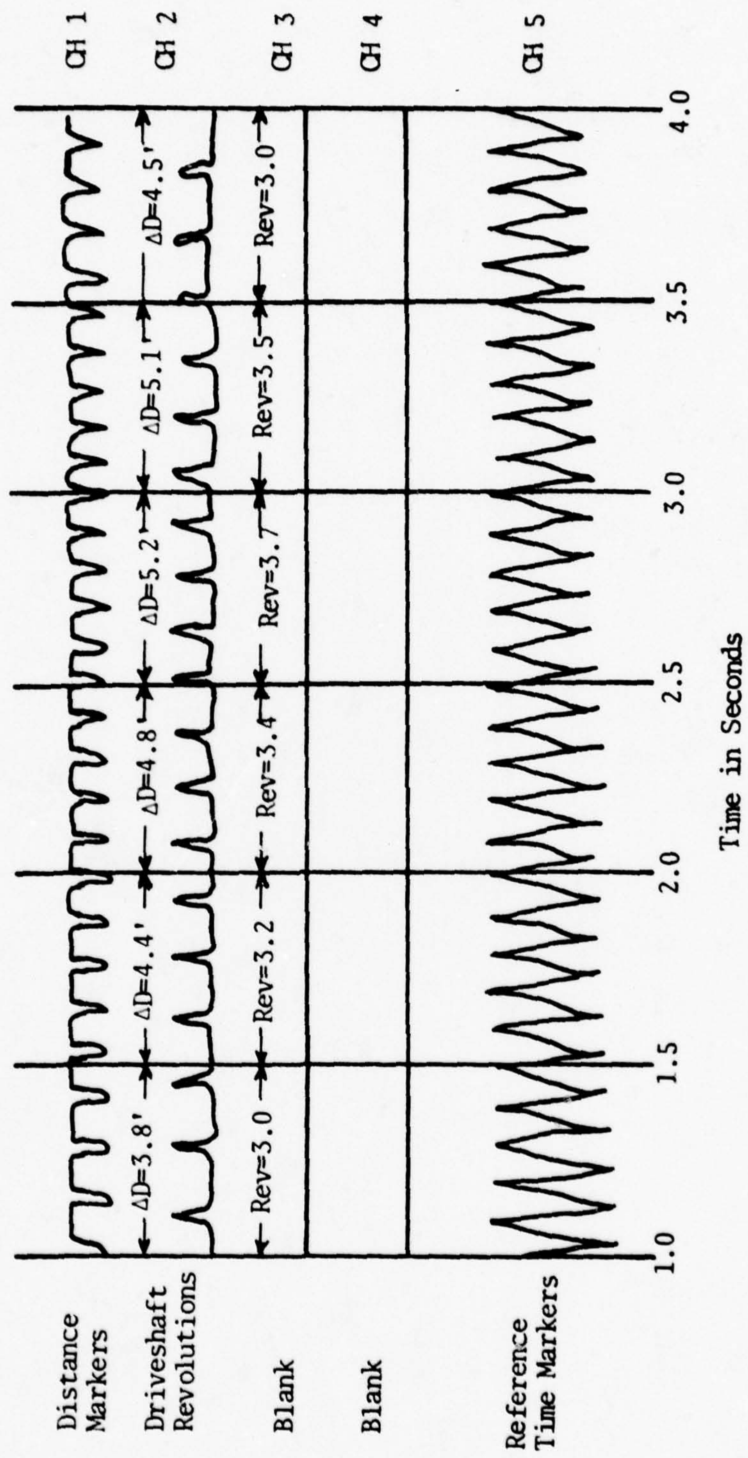

Figure 3. Portion of Typical Time-Distance Recording Obtained in Acceleration-Deceleration Tests for M715

of the test (0 to 1.5 seconds), however, analysis of the recording should be conducted every 0.1 second to ensure that a proper value for maximum acceleration can be derived. The maximum acceleration of the vehicle invariably occurs during this early phase of the test.

6.4.2 A vertical line is then drawn on the chart to facilitate computation of distance traveled and speed of wheel revolutions per time interval. Having previously instrumented the vehicle in order that one event marker per foot of travel would be obtained, channel (CH) 1 can be analyzed for distance by merely counting the number of event markers in a given time interval, as shown in figure 3 where D equals distance.

6.4.3 Next, the speed of revolution of the driveshaft is considered. This is extremely important because these data show how far the vehicle *should have moved* during each time interval, and hence the amount of slip of the drive wheels or tracks. If the slip exceeds 20 percent, the test results obtained are questionable.

6.4.4 Using the above data, velocity is computed for the various time intervals as follows:

V = Velocity
ΔD = Distance vehicle has moved in time Δt
$\Delta D = 502$ ft
Δt = Time interval during which vehicle has moved
$t_1 = 2.5$ sec
$t_2 = 3.0$ sec

$$V = \frac{\Delta D}{\Delta t}$$

$$V = \frac{5.2 \text{ ft}}{0.5 \text{ sec}}$$

$V = 10.4$ ft per second

In order to check the reliability of the acceleration data, percent slip of the wheels is computed as follows:

$$\text{Percent Slip} = \frac{\text{Distance Wheels Moved - Distance Vehicle Moved*}}{\text{Distance Wheels Moved}} \times 100$$

where the distance the wheels moved is the number of revolutions of the driveshaft times the distance the wheel moves for each revolution of the driveshaft.**

* Distance vehicle moves is determined from the payout line.
** Distance wheels move for each revolution of the driveshaft can be determined experimentally by driving the vehicle on a hard surface and noting the distance the wheel moves for each event marker on Channel 2.

After all recordings have been analyzed in the above manner, acceleration-deceleration curves can be plotted for this example as shown in figure 4. From this type of curve the maximum acceleration and average deceleration can be computed as illustrated.

6.4.5 The analysis of the second phase of the Acceleration/Deceleration test yields the braking coefficient of the test vehicle. The average deceleration in this phase equals the braking coefficient and is computed in the same manner as is the average deceleration of the first phase.

6.5 Slope Negotiation. The analysis necessary for these tests consists of plotting the slope negotiating capabilities of the various test vehicles on a go no-go basis for various soil types and strengths. A point to remember is that for a given soil type (fine or coarse-grained soil) and strength, the maximum drawbar pull coefficient closely approximates the tangent of the maximum slope that the vehicle can negotiate.

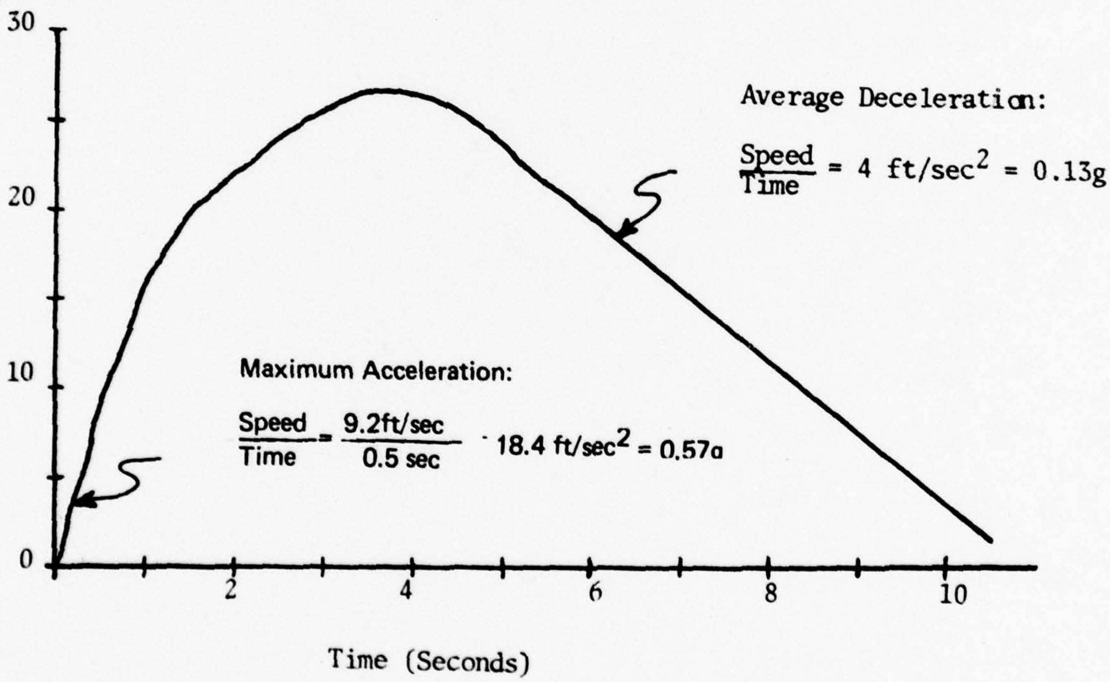

Figure 4. Typical Acceleration/Deceleration Curve

6.6 Discrete Obstacle The analysis of the obstacle crossing data consists of noting whether the test was in a go or no-go condition and estimating the principle cause, e.g., slope, geometric interference, soil strength, of the go, no-go results. Knowledge of the size, shape, and kind of obstacle that a vehicle can and cannot surmount or which slows it down is required in estimating effects of discrete obstacles on vehicle mobility.

6.7 Single-Tree Override This test is designed to measure the maximum force required to fail and override a tree. These forces can be read directly from the chart recordings, with the maximum failure force nearly always occurring just prior to tree failure (as the stem breaks or bends, or as the tree is up-rooted or its root structure is broken). The maximum override force may occur during any portion of the chart recording. These forces are plotted against tree stem diameters in the tree failure portion of the test (figure 5). The override forces are plotted against the tree failure forces to determine if there is a significant difference in overriding an already failed tree.

6.7.1 Two things should be highlighted in a plot of failure force versus stem diameter: the tractive force and the motion resistance force.

6.7.1.1 The tractive force represents the maximum force the test vehicle is capable of applying against a tree, and for this type of test should be presented on the plot as an upper limit of vehicular performance. This is crucial in considering that the tractive force may have been exceeded through the winching action of pulling the test vehicle across the challenged tree, and without this maximum capability represented on the plot, the operator may exceed the strength of the leading edge of the vehicle.

6.7.1.2 The second highlight is the motion resistance. This is the force required to overcome the inherent resistance of the vehicle towards movement, and represents the force to fail a tree of zero stem diameter on a stem diameter versus failure force curve. Hence, the plotted curve should intersect the force-axis at the motion resistance force value. The curve will probably have the form

$$\text{Force} = \text{Motion Resistance} + a\,(\text{Stem Diameter})^{b}$$

where a and b are empirical constants to be solved through appropriate field tests and a mathematical curve fitting routine.

6.8 Multiple-Tree Override The data gathered in this test differ from the single-tree test in that the forces to fail and override cannot be separated. This occurs because while one tree is being failed another

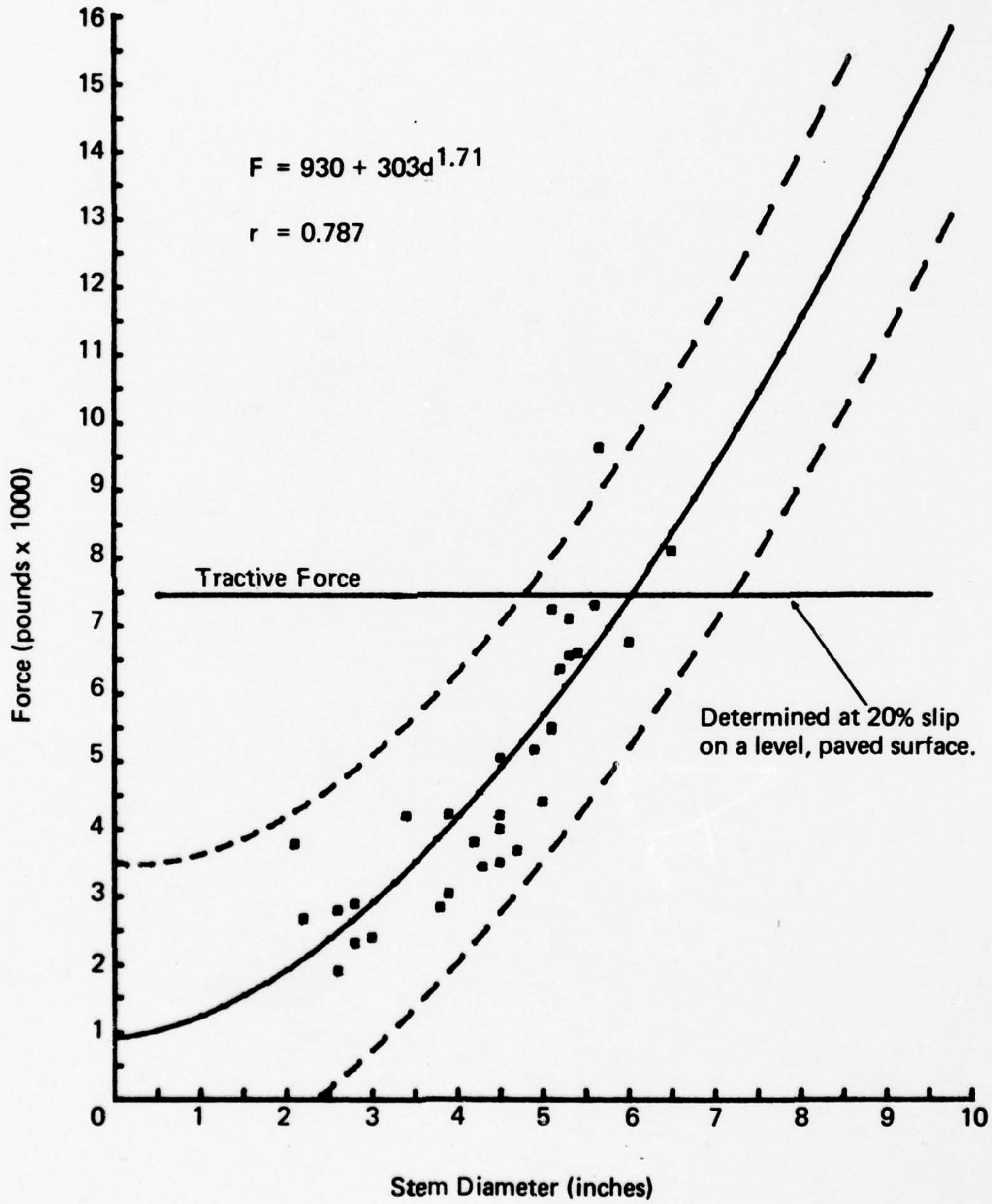

Figure 5. Force Required to Override a Tree with M715, 5/4-Ton Truck

is being overridden. However, close observation of the chart recordings will reveal peak forces occurring at intervals that are dependent upon the spacing of the trees being overridden. The procedure for data analysis matches each force to the tree which was overridden and then uses the average force, which will correspond to an average tree diameter, to plot this against the single tree predicted force for the same size tree (obtained from the curve of force-to-fail versus single-tree stem diameter). After a series of single- versus multiple-tree forces have been plotted (obtained from several multiple tree tests), a curve can be fitted to the data pairs to obtain a relation between single- and multiple-tree failure override forces. Previous tests have shown that this relationship is linear (figure 6).

6.9 Grassland Override Data gathered during this test indicate the averaged force measured while grass is overridden on the first and second passes. These data are then presented in tabular form (when more than one type of vehicle is used for the test) showing both averages and the percent increase in force caused by the override on the first pass.

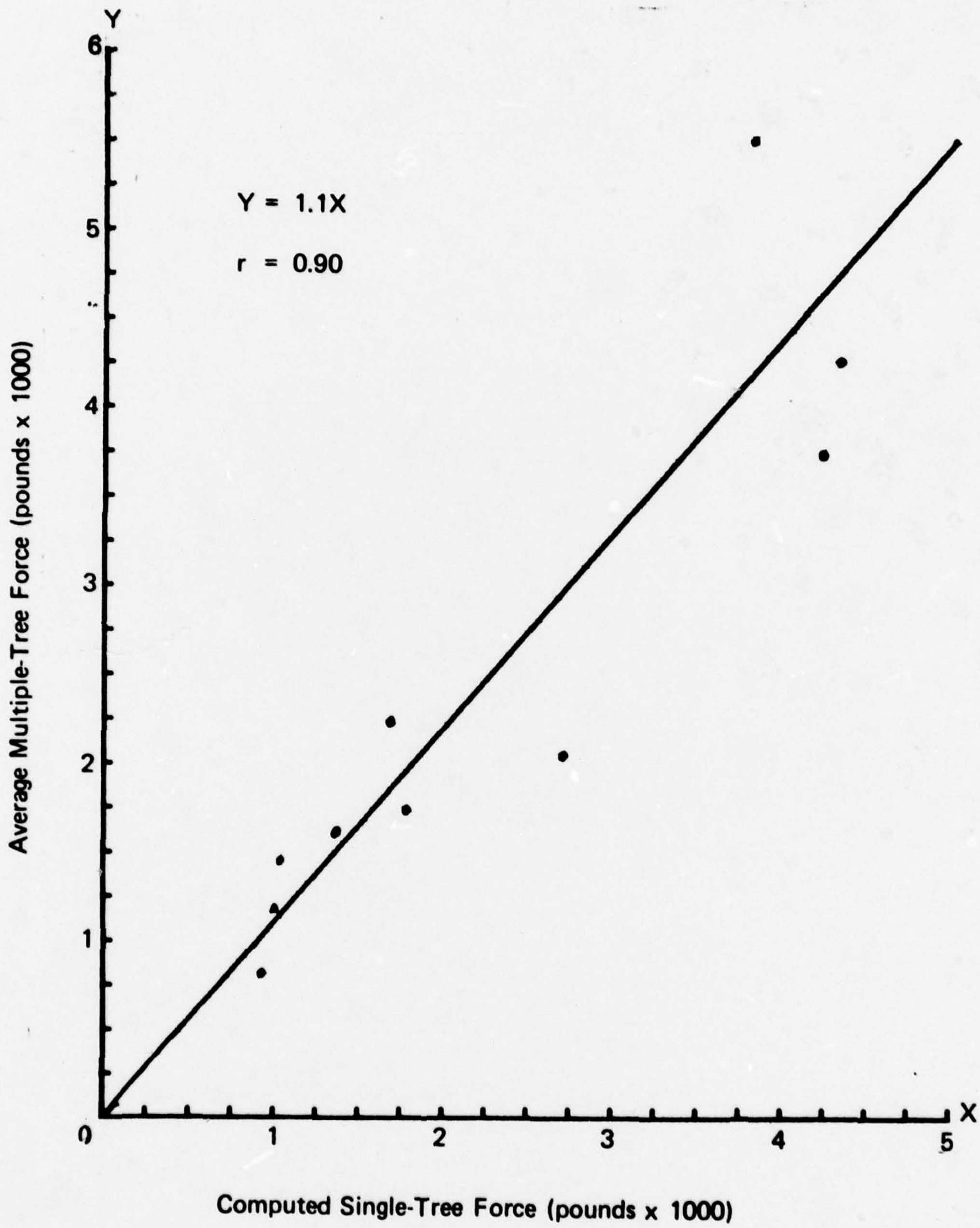

Figure 6. Single- versus Multiple-Tree Force Required to Override

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APPENDIX A. DATA COLLECTION FORMS

Table A-1. Soil Data Form

Type Test_______________ Date_______________ Location_______________

1. USCS Soil Type Classification:	0- to 6-Inch Depth Sample 1	6- to 12- Inch Depth Sample 2
Can Number		
Soil Type		

2. Soil Moisture Content, %:

Depth (Inches)	Can Number	
	Sample 1	Sample 2
0-1		
1-6		
6-12		

Results of Lab Analysis	Sample 1 Depth (Inches)	Sample 2 Depth (Inches)
Moisture Content, %	0-1 1-6 6-12	0-1 1-6 6-12
Dry Density, lbs/cuft	0-6 6-12	0-6 6-12

3. Remolding Index (RI):

Cone Index (CI)		
Depth (Inches)	Depth in Inches	
	Before 100 blows	After 100 blows
0		
1		
2		
3		
4		
5		
6		
Total		

Computation of RCI

$$RI = \frac{\Sigma \text{ Cone Indices after remolding}}{\Sigma \text{ Cone Indices before remolding}}$$

RCI = (RI) (CI)

RCI = ____________________

Table A-1 (cont)

4. Before Traffic Cone Index:

Distance Feet Along Test Lane											
Depth, in		0	10	20	30	40	50	60	70	80	90
0	R* L*										
1	R L										
2	R L										
3	R L										
4	R L										
5	R L										
6	R L										
9	R L										
12	R L										
Total											
Average											

5. Rut depth when vehicle immobilization occurred (inches) __________

6. Section of test lane in which immobilization occurred __________

7. Identification of test vehicle __________

8. Driver's name __________

* R-Right Rut; L-Left Rut

NOTE: This data form can be used for other soil-vehicle tests.

Table A-2. Slope Data Form

Test Vehicle_______________ Date__________ Location_______ Driver__________

1. Soil data at point where vehicle immobilization occurred (see Table A-1).

   ____

2. Slope (%) on course where vehicle immobilization occurred_____________

3. Vertical distance (in) from vehicle CG to ground (h) _______________

4. Distance (in) from CG to point perpendicularly beneath center of rear axle (d) ____

5. Description of the terrain along test lane _______________________

   ____

   ____

   ____

   ____

Table A-3. Tree Failure and Override Data Form

Test Vehicle__________ Date__________ Location_______ Driver_______

1. Vegetation Data

   a. Stem diameter (in) at breast height (DBH) __________

   b. Vegetation type __________

   c. Mode of tree failure __________

2. Vehicle Characteristics

   a. Identification __________

   b. Test weight __________

   c. Bumper height (in) __________

   d. Ground clearance (in) __________

3. Force Data

   a. Force required to fail tree, lb __________

   b. Force required to override tree, lb __________

4. USCS Soil Type Classification

	Depth of Sample	
	0-6"	6-12"
a. Can Number		
b. Soil-type		

5. Soil Moisture Content, %

	Depth of Sample	
	0-6"	6-12"
a. Can Number		
b. Moisture Content, %		

Table A-3 (cont)

6. Cone Index

Cone Index		
Depth (Inches)	Sample 1	Sample 2
0		
1		
2		
3		
4		
5		
6		
9		
12		
18		
Average 0-6"		
Average 6-12"		
Average 12-18"		

APPENDIX B. COMPUTATION OF VCI

1. To compute VCIs for fine-grained soil, a mobility index (MI)* is computed as follows:

Self-Propelled All-Wheeled-Drive Vehicles:

$$\text{Mobility Index} = \left[\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{tire factor} \times \text{grouser factor}} + \text{wheel load factor} - \text{clearance factor} \right] \times \text{engine factor} \times \text{transmission factor}$$

where

(1) Contact pressure factor = $\dfrac{\text{gross weight, lb}}{\text{nom. tire width, in.} \times \dfrac{\text{outside diam of tire, in}}{2} \times \text{No. of tires}}$

(2)

Gross weight, lb / No. of axles		Weight Factor Equations
Weight	<2,000	Y = 0.553X
2,000 to	13,500	Y = 0.033X + 1.050
13,501 to	20,000	Y = 0.142X - 0.420
	>20,000	Y = 0.278X - 3.115

where
Y = weight factor
X = $\dfrac{\text{gross weight, kips}}{\text{No. of axles}}$

(3) Tire factor: $\dfrac{10 + \text{tire width, in.}}{100}$

(4) Grouser factor: With chains = 1.05
Without chains = 1.00

(5) Wheel load factor : $\dfrac{\text{Gross weight, kips}}{\text{No. of axles} \times 2}$

(6) Clearance factor: $\dfrac{\text{clearance, in.}}{10}$

(7) Engine factor: ≥10 hp/ton = 1.00
<10 hp/ton = 1.05

(8) Transmission factor: Automatic = 1.00
Manual = 1.05

*Dimensionless number determined from a formation of certain vehicle characteristics.

Self-Propelled Tracked Vehicles:

$$\text{Mobility index} = \left[\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{track factor} \times \text{grouser factor}} + \text{bogie factor} - \text{clearance factor}\right] \times \text{engine factor} \times \text{transmission factor}$$

where

(1) Contact pressure factor $= \dfrac{\text{gross weight, lb}}{\text{area of tracks in contact with ground, sq in.}}$

(2) Weight factor:

Less than 50,000 lb = 1.0
50,000 to 69,999 lb = 1.2
70,000 to 99,999 lb = 1.4
100,000 lb or greater = 1.8

(3) Track factor = $\dfrac{\text{track width, in}}{100}$

(4) Grouser factor:

Grousers less than 1.5 in high = 1.0
Grousers more than 1.5 in high - 1.1

(5) Bogie factor = $\dfrac{\text{gross weight, lb, divided by 10}}{\left(\text{total number of bogies on tracks in contact with ground}\right) \times \left(\text{area, sq in., of 1 track shoe}\right)}$

(6) Clearance factor = $\dfrac{\text{clearance, in.}}{10}$

(7) Engine factor:

$\geq$ 10 hp/ton of vehicle wt = 1.00
< 10 hp/ton of vehicle wt = 1.05

(8) Transmission factor: Automatic = 1.0; manual = 1.05

2. After computing of the mobility index, VCIs are obtained using the following equations:

Self-Propelled All-Wheeled-Drive Vehicles:

(1) One-Pass VCI $VCI_1 = 11.48 + 0.2\ MI - \left[\dfrac{39.2}{MI + 3.74}\right]$

(2) Fifty-Pass VCI $VCI_{50} = 28.23 + 0.43\ MI - \left[\dfrac{92.67}{MI + 3.67}\right]$

Self-Propelled Tracked Vehicles:

(1) One-Pass VCI $$VCI_1 = 7.0 + 0.2\ MI - \left[\frac{39.2}{MI + 5.6}\right]$$

(2) Fifty-Pass VCI $$VCI_{50} = 19.27 + 0.43\ MI - \left[\frac{125.79}{MI + 7.08}\right]$$

3. A typical example resulting from using the above equations is as follows:

<u>Mobility Index and VCI for M715 1 1/4-Ton Truck</u>

Computation of Mobility Index:

(1) Contact pressure factor $\dfrac{8000}{9 \times \frac{34}{2} \times 4}$ = 13.07

(2) Weight factor 0.033 x 4 + 1.050 = 1.18

(3) Tire factor $\dfrac{10 + 9}{100}$ = 0.19

(4) Grouser factor = 1.00

(5) Wheel load factor $\dfrac{8}{2 \times 2}$ = 2.00

(6) Clearance factor $\dfrac{10}{10}$ = 1.00

(7) Engine factor = 1.00

(8) Transmission factor = 1.05

$$\text{Mobility Index} = \left[\frac{13.07 + 1.18}{0.19 \times 1.00} + 2.0 - 1.0\right] \times 1.0 \times 1.05 = 86.26$$

Computation of VCI:

(1) $$VCI_1 = 11.48 + 0.2 \times 86.26 - \left[\frac{39.2}{86.26 + 3.74}\right] = 28$$

(2) $$VCI_{50} = 28.23 + 0.43 \times 86.26 - \left[\frac{92.67}{86.26 + 3.67}\right] = 64$$

APPENDIX C. TEST SITE PARAMETERS

1. Gamboa A-1 Test Area. This area covers approximately 6600 hectares (6300 acres) and is located near the town of Gamboa in the central part of the Canal Zone (figures C-1 and C-2). A road built for pipeline maintenance traverses the area and provides access to the test sites. Description of the sites recommended for use in this area follows:

a. Sites A, B, C and D (figure C-1, inset). Vegetation at all sites is primarily Tropic Moist Forest as defined by the Holdridge Life Zone system of classification.[5] The vegetation in the area is approximately 30-year-old secondary growth. A few large emergent trees (remnants from a previous forest) are scattered throughout the test area. Vegetation closest to the Pipeline Road is primarily tropical grasses, Gynerium Sagittatum (figure C-3). This grass is 3 to 6 feet (0.9 to 1.8 meters) tall except where cut or burned. The vegetation farther from the road is a relatively uniform stand of advanced secondary growth 30 to 40 years old (figure C-4). The tree species represent those normally associated with secondary growths, i.e., *Miconia* sp, *Apeiba* sp, *Annona* sp, *Luehea* sp, *Cochlospermum* sp, *Cecropia* sp, and *Guazuma* sp. However, a few mature forest species exist. Generally the trees are young and have not yet attained their mature stature. The relative youth of the forest in this area provided an open canopy that subsequently formed the dense undergrowth characterized by shrubs, herbs, and vines. This undergrowth can provide sufficient resistance and obscuration to impede movement of both man and vehicles. Soils in the test sites are uniform and primarily fine-grained, classified as MH according to the Unified Soil Classification System.[6] The drainage within the test sites prevents inundation or puddling of water, hence the soil is relatively firm throughout the year. Average cone index of the 0-6-inch (0 to 15.2 cm) layer is 240.

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[5] The Forest Environments in Tropical Life Zones, Permagon Press, N.Y., 1971.

[6] Unified Soil Classification System, USAWES Technical Memo No. 3-357, Vol 1, March 1953 (Revised April 1960).

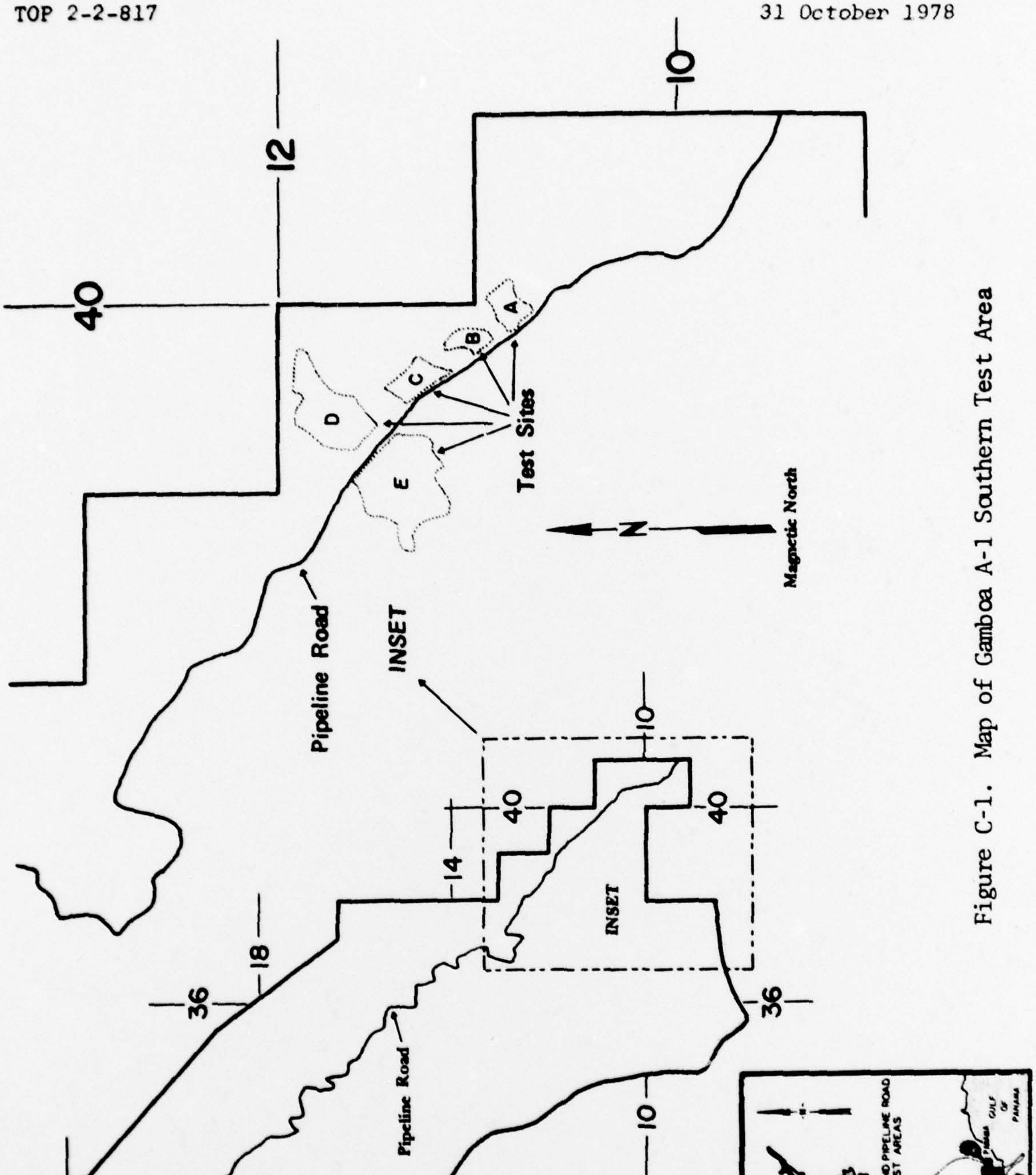


Figure C-1. Map of Gamboa A-1 Southern Test Area

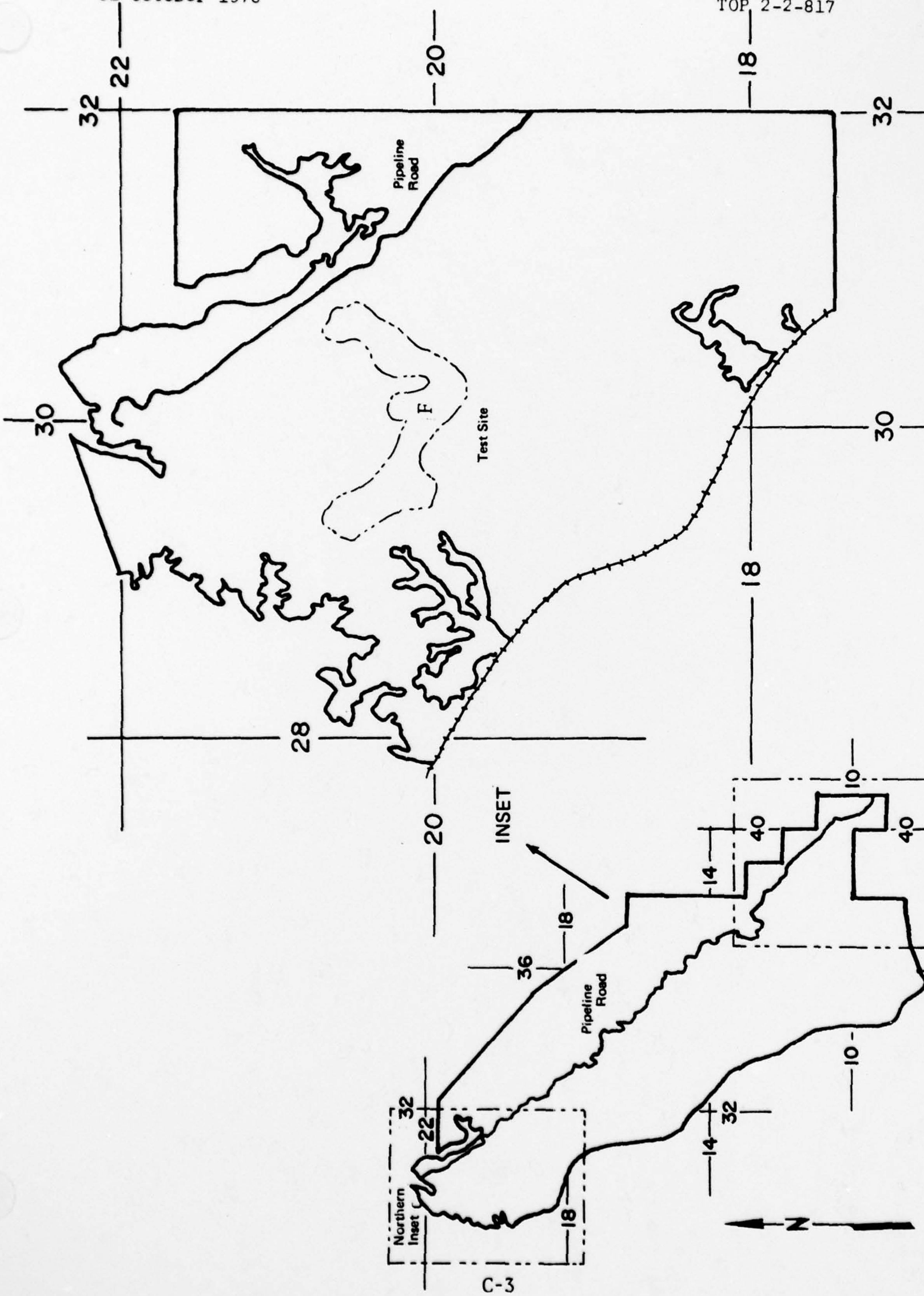


Figure C-2. Map of Gamboa A-1 Northern Test Area

Figure C-3. Grassland Area Along Pipeline Road

Figure C-4. Secondary Vegetation Growth - 30 to 40 Years Old

b. Site E[(figure C-1, above (inset)]. Terrain characteristics at this site are similar to sites A through D. The site is predominantly covered by grass in the northern section while the southern section is an open secondary forest up to 20 years old. Trees are up to 45 feet (14 meters) tall with an open canopy; some grass areas are found under the canopy. A typical view of the grasslands found at this site is shown in figure C-5.

Figure C-5. M151A1, ¼-Ton Truck Entering a Grassland Test Area

c. Site F[figure C-2, above (inset)]. The terrain at this site ranges from flat to gently rolling with most slopes ranging from 0 to 10 percent; some slopes are 55 percent. There are no abrupt surface features; all hills are smooth and rounded. Little inundation occurs since definite surface drainage patterns are established. Soil at the site is fine-grained, classified as MH. Vegetation at the site is uniform in density and consists of tall tropical grass that reaches a height of 6 feet (2 meters) or more. A typical view of the site is shown in figure C-6.

Figure C-6. Grassland Test Area

2. Venado Test Area. This area is located on the west side of the Canal between Howard Air Force Base and the village of Vera Cruz. The map at figure C-7 shows the location of the three test sites selected for use in tropic vehicle tests.

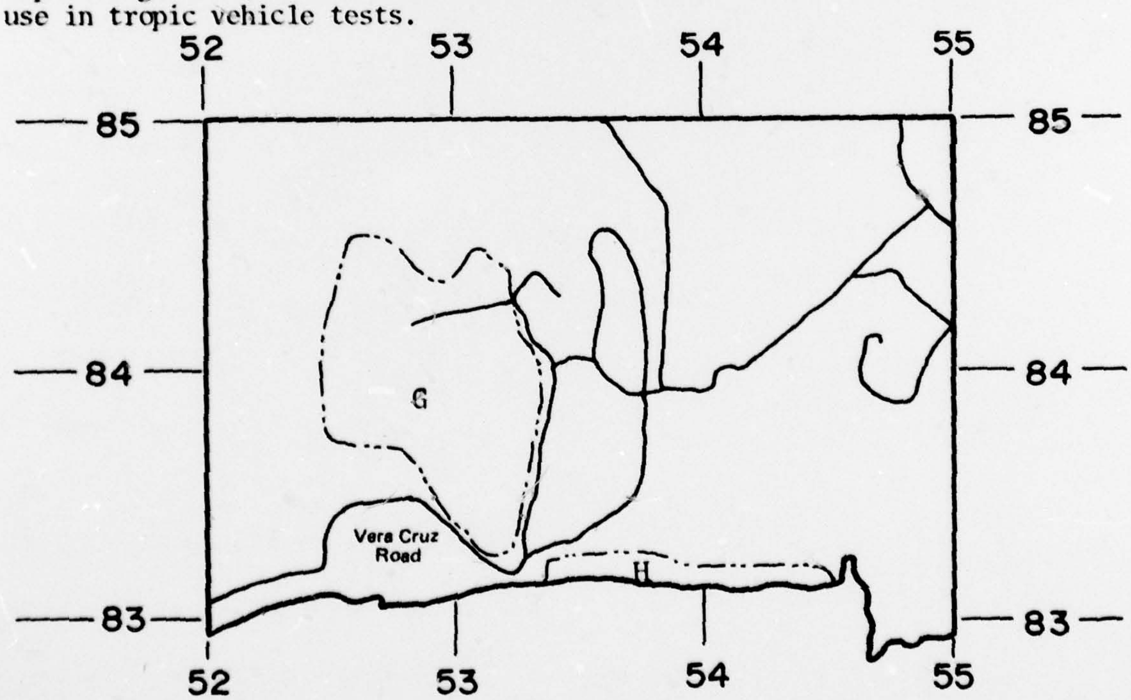


Figure C-7. Venado Test Sites - Drop Zone and Beach

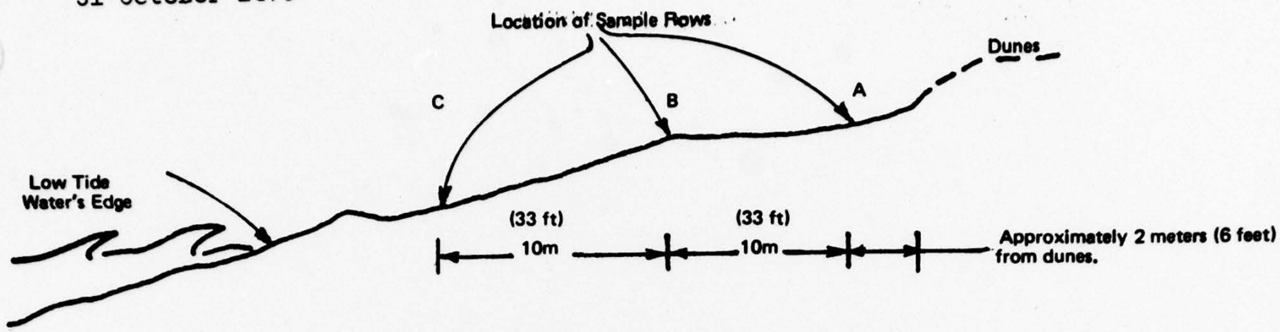
a. Site G (figure C-7). This site is known as the Venado Drop Zone and is for airborne operation testing. A general view is shown in figure C-8.

Figure C-8. Venado Drop Zone Test Site

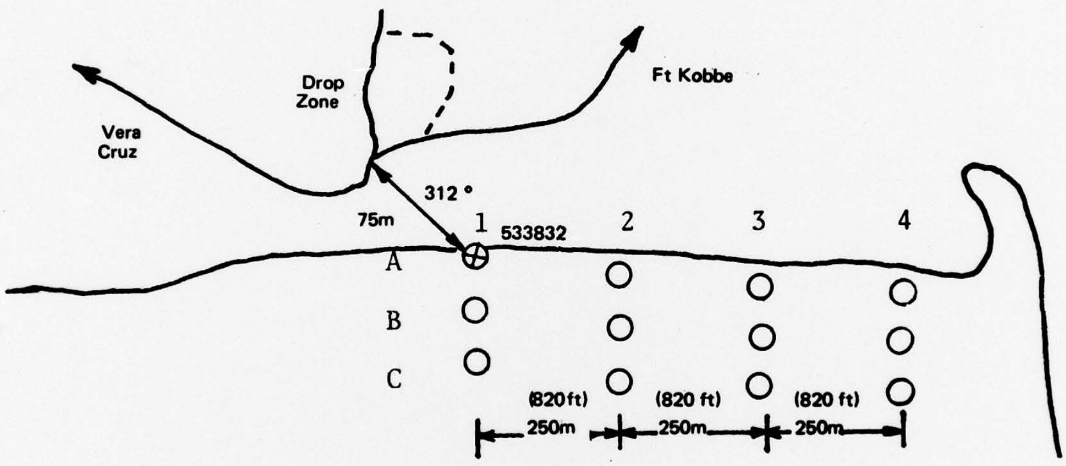
The site is mostly level with 90 percent of the area having less than a 2-percent slope. The extreme eastern portion has slope ranges varying from 3 to greater than 45 percent. An intermittent drainageway roughly bisects the area, and inundation occurs adjacent to the drainageway for short periods immediately following heavy rain. Vegetation is uniform throughout the area. The Drop Zone proper is grass-covered and is ringed with secondary growth vegetation on the eastern and northern sides. The soils are fine-grained and have average wet season cone indexes ranging from 22 in wet bottom lands to greater than 300 on upland slopes.

b. Site H (figure C-9). This portion of the Venado Test site is a long smooth beach with little or no slope. Soils are mostly clean sand mixed with some broken corals and shell fragments. There is no significant vegetation on the site. A general view of the beach site is shown in figure C-9; a vertical profile and cone index data at low tide are shown in figure C-10.

Figure C-9. General View of Venado Beach Test Site at Low Tide



a. Vertical Profile of Beach at Low Tide



TEST ROW SURFACE			0"	1"	2"	3"	4"	5"	6"	9"	12"	0-6"	6-12"
Row	A	1	0	10	28	50	65	88	165	220	165	58	183
	B	1	5	30	65	78	125	190	180	225	300+	96	235+
	C	1	5	15	35	64	125	210	255	300	300+	101	285+
	A	2	5	18	38	62	118	160	150	300	300+	79	250+
	B	2	15	32	68	105	145	180	230	300	300+	111	277+
	C	2	3	12	22	33	58	60	68	180	300+	37	182+
	A	3	0	20	26	45	80	160	210	300+	300+	77	270+
	B	3	10	30	75	85	160	215	260	300+	300+	119	287+
	C	3	15	33	56	60	70	65	80	130	90	54	100
	A	4	5	22	50	120	280	300	300+	300+	300+	154+	300+
	B	4	25	58	103	155	190	225	300+	300+	300+	151+	300+
	C	4	12	29	46	58	85	115	140	160	175	69	158

b. Cone Index Sampling Points and Values Obtained

Figure C-10. Description of Venado Beach Test Site

a. Approach Lane for Single-Tree Override Tests

b. Single-Tree Override Test Site Cleared of Dense Undergrowth

Figure C-11. Area Prepared for Single-Tree Override Tests

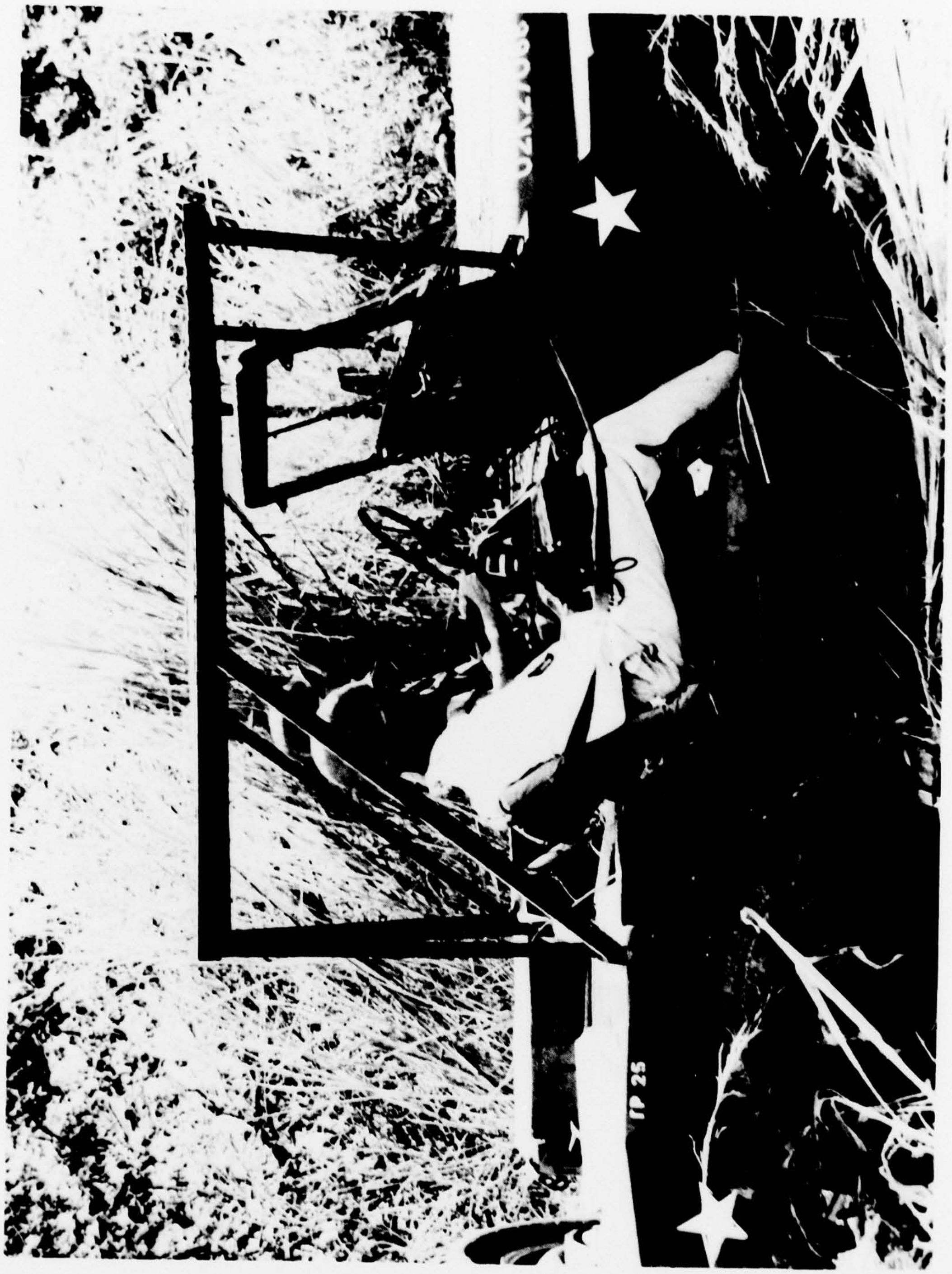


Figure C-12. Vehicle With Protective Cage Installed

a. Measurement of Cone Index

b. Measurement of Tree-Diameter at Breast Height

Figure C-13. Terrain Factor Measurements Being Made Prior to Single-Tree Override Tests

Figure C-14. Vehicle in Position for Single-Tree Override Test